Induction Motor Control

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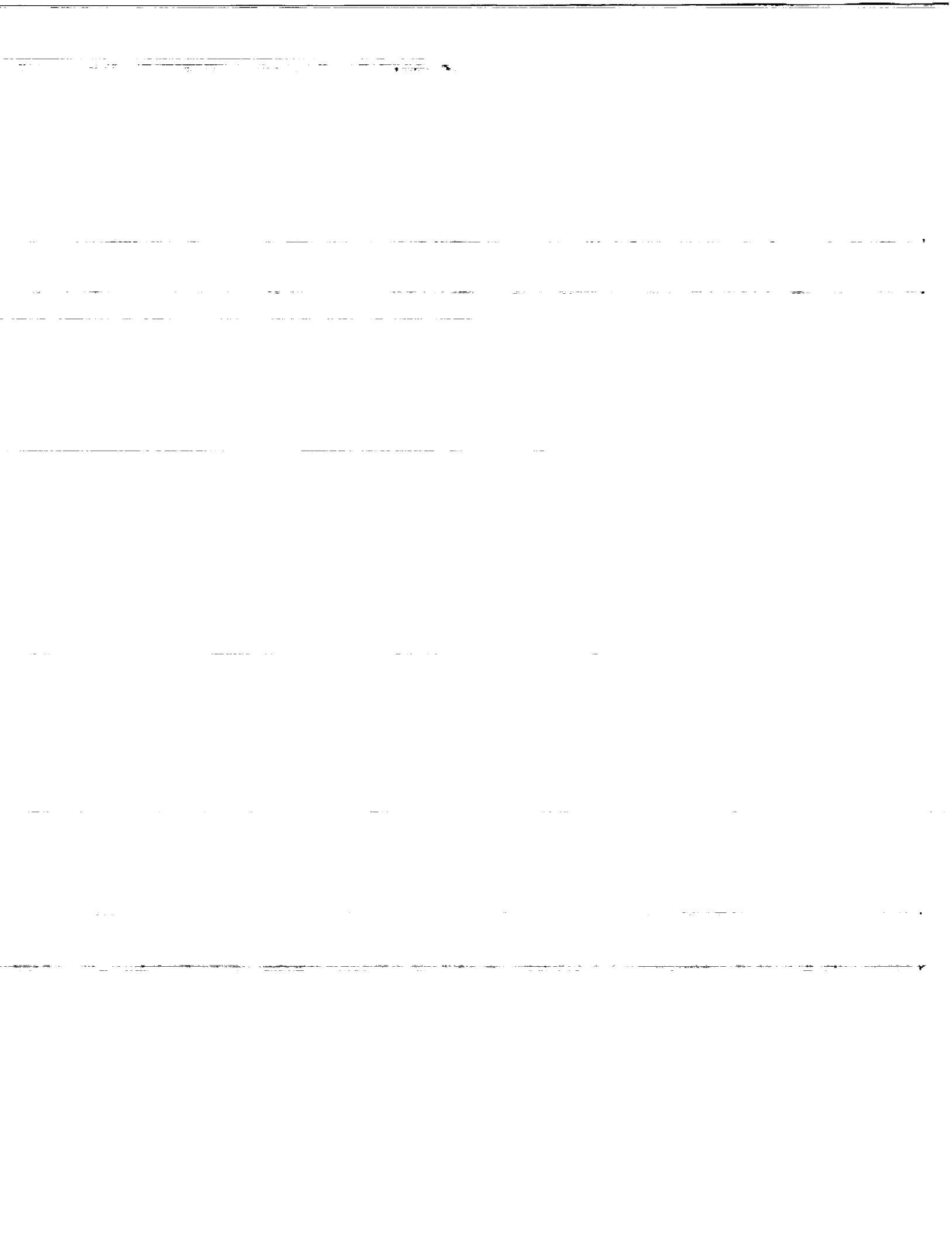
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Electromechanical actuators developed to date have commonly utilized permanent magnet (PM) synchronous motors. More recently switched reluctance (SR) motors have been advocated due to their robust characteristics. This paper will discuss implications of the work being performed at NASA Lewis Research Center and their contractors which utilizes induction motors and advanced control techniques. When induction motors are operated from an energy source capable of controlling voltages and frequencies independently, drive characteristics are obtained which are superior to either PM or SR motors. By synthesizing the machine frequency from a high frequency carrier (nominally 20 kHz), high efficiencies, low distortion, and rapid torque response are available. At this time multiple horsepower machine drives have been demonstrated, and work is on-going to develop a 20 hp average, 40 hp peak class of aerospace actuators. This effort is based upon high frequency power distribution and management techniques developed by NASA for Space Station Freedom.

Induction Motors

Induction motors have, in general, been acknowledged to be not only rugged and relatively inexpensive, but are also considered to be relatively inefficient and difficult to control. Several recent technical developments have overcome these limitations and allow use of the induction motor in a wide range of applications, which exploit its robustness, its high temperature capabilities, and its immunity to catastrophic stator shorts.

Induction Motor Characteristics

The induction motor, reduced to its most elemental form, is a transformer having a radial field primary and a moveable, coaxial, secondary. Two currents are involved, the primary (stator) current and the secondary (rotor) current (Fig. 11). The air-gap flux is established by the stator current which is proportional to the applied voltage, and inversely proportional to the frequency. The rotor current is induced by the air-gap flux and is proportional to the rate of change of the field as sensed by the rotor conductors in the stator field. An induction motor in its simplest form has a stator field capable of "rotation" with a magnitude proportional to the ratio of the applied voltage to frequency, and a reacting rotor current proportional to the rotation (rate of change) between the stator field and the rotor conductors. When the applied voltage and frequency are independently controlled, the rotor and stator currents are independently controlled. Additionally, the rate dependant rotor current along with its associated torque production may be changed instantly (subject only to conservation laws).

Field Oriented Control

In as much as the energy in both the rotor and stator field must be provided by the stator current, the net stator current consists of the vector resultant of the flux causing current and the torque causing current. This vector addition concept is embodied in several field oriented or flux vector control schemes,[1] which form the basis of modern induction motor control techniques.

Pulse Population Modulation (PPM)

Electrical power is delivered by a high frequency link,[2] and can easily be used to synthesize lower frequencies. A synthesized 400 Hz waveform is shown in Fig. 2. In such a waveform, the voltage is controlled by the density of the pulses (population), and the frequency is controlled by the waveform pattern. In practice, the motor is excited by three such waveforms having the usual 120° displacements. Because the density patterns have these same displacements, the net pulse density pattern is uniform and a constant load is reflected back upon the link. All switching functions are performed at 0 V resulting in low switching losses. What may be more important, however, the switches are operated at the carrier frequency, not the machine frequency, resulting in physically small reactive elements. Reduced component loss and volume will be reflected in major reductions in the size and mass of motor drive electronics and its cooling compared to PWM brushless motor technology.

Induction Motor Characteristics

Several constant voltage and frequency operational characteristics of a 400 Hz aircraft induction motor are shown in Fig. 3.[3] Of particular interest are the characteristics for speeds greater than that corresponding to maximum horsepower. This region is shown in greater detail in Fig. 4, and represents the usual steady state operation of an induction motor.

Further examination of the characteristics corresponding to speeds around 11 250 rpm shows low slip frequencies, low loss, and full rate output. Independent control of voltage and frequency allows the motor to display these characteristics at any speed.

Torque speed characteristics obtainable by increasing the supply voltage and frequency equally are shown in Fig. 5. Within the limits illustrated by Fig. 6, the motor may be operated at its optimum characteristics at any speed including zero speed or negative speeds (generation).

Rotor Loss

The I^2R rotor loss of an induction motor is an often cited disadvantage. As seen in Fig. 7, the need for high low speed torques for starting have historically required high rotor resistance and high slip frequencies; consequently, high losses were experienced (Fig. 7).

However, if slip frequencies and stator field are independently controlled, peak starting torque may be developed by a very low resistance rotor. Under such conditions, the applied voltage is low, the current is low, and the rotor (I^2R) loss is low. In any event, due to its simple construction, the rotor temperature is limited only by the insulation of the low voltage rotor conductors.

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For such applications, a properly controlled induction motor provides ruggedness, high peak torques, and good efficiencies over the full operating range.

Conclusion

The ultimate limit for electric actuators has always been the electronics (and probably always will be). Therefore, always operating the motor at its most optimum conditions is crucial in this respect.
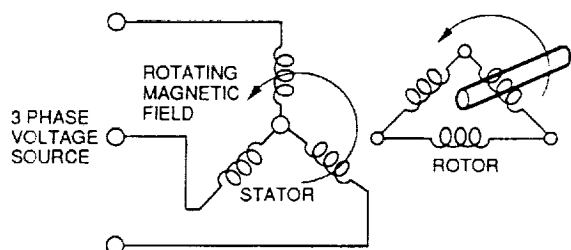
The induction motor combined with advanced control has marked advantages when compared to switched reluctance and permanent magnet motors.

References

1. P.T. Walter, and F.N. Klein, "Vector Control Gives AC Drive The Edge Over DC," Power Convers. Intel. Motion, vol. 15, pp 60-64, 1989.

2. I.G. Hansen, "Status of 20 kHz Space Station Power Distribution Technology," NASA TM-100781, 1988.

3. Motor 939D228-4, Westinghouse Corp., Lima Division

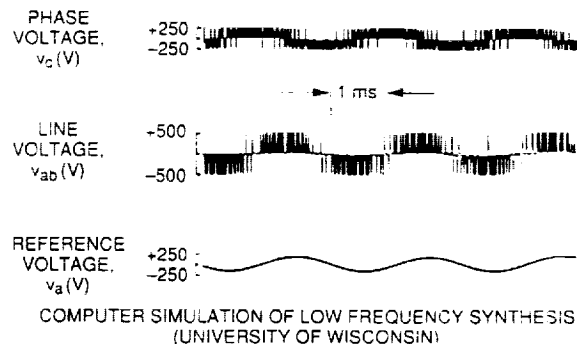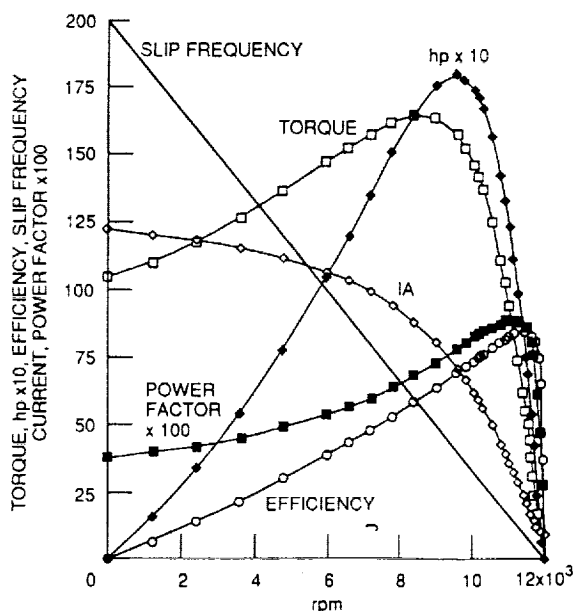Figure 1. - Induction motor.

Figure 2. - Pulse population modulation (PPM).

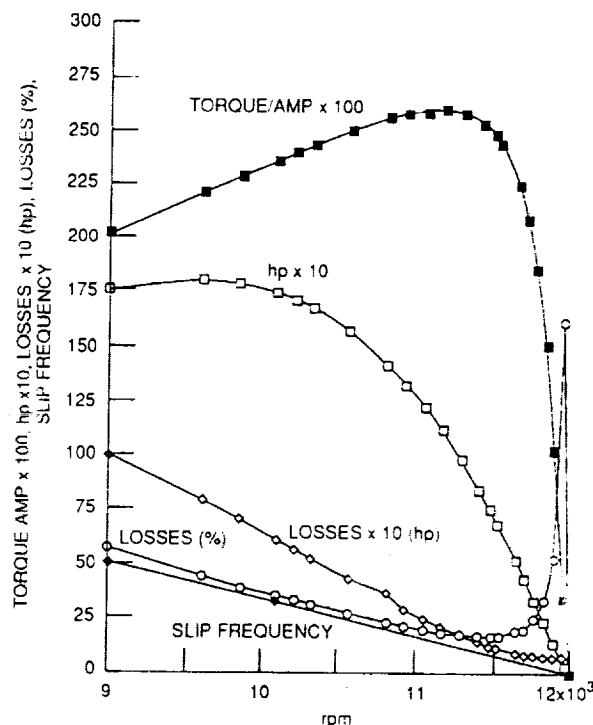Figure 3. - Induction motor characteristics (fixed voltage and frequency).
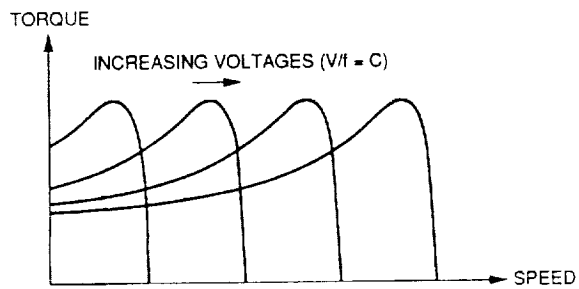
Figure 4. - Data for motor 939D228-4.

TORQUE

INCREASING VOLTAGES (V/f = C)

SPEED

Figure 5. - Constant V/f induction motor.

TORQUE

TORQUE LIMIT

VOLTAGE LIMIT

CONSTANT POWER CURVE
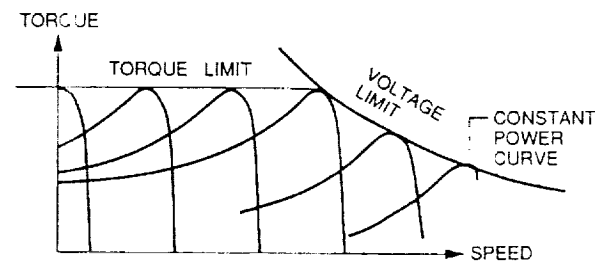
SPEED

Figure 6. - Electronic limitations.

SLIP

R = 8.5   R = 5.5

ROTOR R = 3

ROTOR R = 1

SLIP

T

0
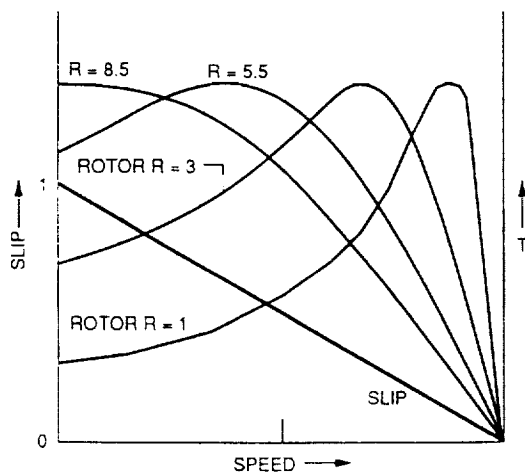
SPEED

Figure 7. - Speed torque characteristics of induction
motor as function of rotor resistance.

POWER ENERGY TO ACTUATORS

HYDRAULIC
CONSTANT PEAK POWER

HYDRAULIC ENERGY

EMA POWER

EMA ENERGY

TIME

LIFT-OFF   MAX Q   CARGO
                        SEPARATION
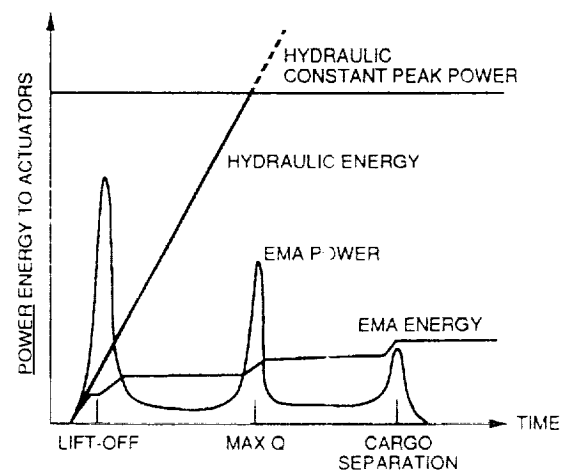
Figure 8. - Power/energy flight profile.

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16. Abstract

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